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# The Fuel Penalty Factor

## Failures Affecting the Fuel Consumption A320 Family and A330/A340

## 1. Introduction

Monitoring the fuel consumption all along a mission is one of the most important tasks of the flight crew. This general statement was already highlighted in the Safety First article "Low Fuel Situation Awareness" published in issue n°6 (July 2008). This article stressed the following points:

► The importance of the different fuel checks in cruise, to detect an abnormal fuel situation

► The functionality limitations of the Flight Management System (FMS) in terms of fuel predictions, under non-nominal aircraft conditions.

In this new article, we will focus on the second theme: The FMS Estimated Fuel On Board (EFOB) predictions do not currently take into account the in-flight failures that have an impact on the fuel consumption. The only exception is the one engine out failure, once confirmed in the FMS. For all other cases, the FMS predictions should be corrected to take into account the consequences of these failures in terms of excessive fuel consumption.

The purpose of this article is to present new developments in terms of:

► Documentation and procedure that have been introduced in November of 2011

► Coming standards of Flight Warning Computers that will soon become available.

These enhancements were designed to improve the crews' awareness of the fuel consumption increase generated by certain failures.

## 2. Failures Affecting the Fuel Consumption

All failures that affect the nominal aerodynamic characteristics of the aircraft will also increase its fuel consumption. The additional drag penalty drag has to be compensated by an increase in thrust (to maintain the same flight conditions) or by a descent to a lower flight level (if there is no thrust margin).

The two main sources of additional drag are:

► A failure affecting the **flight control surfaces,** which may lead to three specific configurations, generating each a different amount of drag:

• The surface is blocked in its full deflection position (runaway), or

• The surface is free and floats in the wind (zero hinge moment position), or

• The surface (only applicable to spoilers) slowly extends over time, after the loss of its hydraulic actuation (spoiler drift, see explanations in box below).

► A failure affecting the l**anding gears** or **landing gear doors retraction function,** which will lead to the gears, or doors, remaining extended.

# SPOILER DRIFT

In case of hydraulic system failure, some spoilers will no longer operate. An anti-extension device will avoid the deflection of the spoiler. However, depending on the condition of the spoiler servo control, this anti-extension device could be sensitive to temperature variations or prone to actuator leak. In that case, the spoiler may not be maintained retracted and may extend over time up to its zero hinge moment position.

Let us consider the cockpit effects of such a failure mode on an A320:

► First, the Hydraulic failure (HYD G SYS LO PR for instance), with all affected spoilers indicated fault retracted in amber on the ECAM Flight Control page (fig. 1A).

► If one of the affected spoilers (n°5 left, for instance) drifts, no indication will appear on the ECAM as long as the extension value remains below 2.5°.

► Once it crosses that threshold, a F/CTL SPLR FAULT amber caution is triggered and the affected spoiler is indicated fault deflected in amber on the ECAM F/CTL page (fig. 1B).

► From then on, it is considered that the affected spoiler generates a non negligible increase of the fuel consumption, which will evolve over time, as the spoiler extends further.

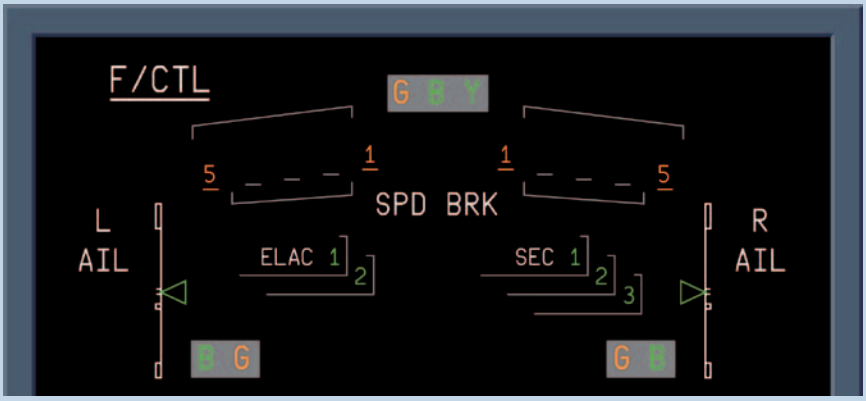


**Figure 1A**
*A320 ECAM F/CTL page: affected spoilers indicated fault retracted*

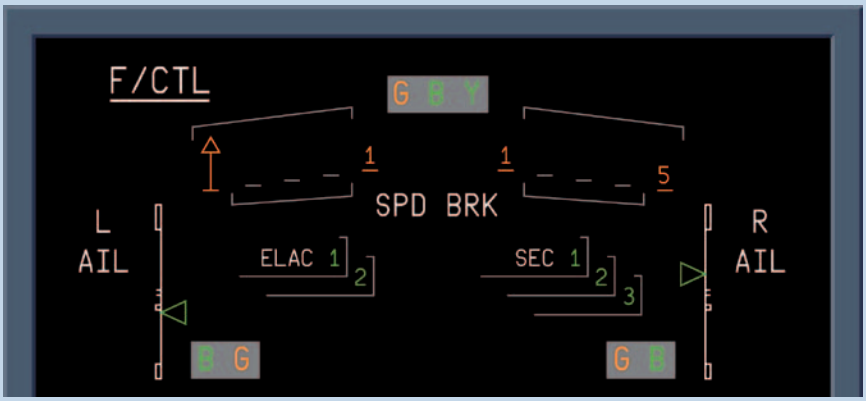


**Figure 1B**
*A320 ECAM F/CTL page: spoiler n°5 indicated fault deflected*

We can segregate these failures into four systems : ELEC, F/CTL, HYD, L/G.

**note**

Indeed, as the flight control surfaces are all electrically controlled, and hydraulically activated, some ELEC and/or HYD failures will lead to the loss of flight control surfaces (ailerons and/or spoilers).

**Figure 1C**
*Illustration of spoiler drift on an A330*

# MULTIPLE FAILURES

Some faults that independently do not generate any fuel consumption increase can, if combined, lead to an overconsumption. This can be due to in-flight failures, or more likely, to the combination of a dispatch under MEL followed by an in-flight failure. This kind of combination has to be taken into account in the failure cases generating a fuel consumption increase.

To illustrate the concept of multiple failures, let us consider an example on the A330. The general architecture of the aircraft's flight control system is is illustrated in fig. 2A.

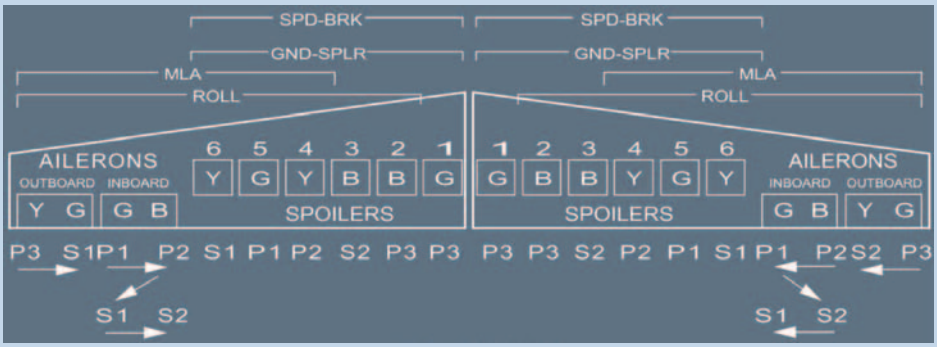


**Figure 2A**
*A330 Flight Control Architecture*

The aircraft may be dispatched with PRIM3 inoperative under MEL. This implies that two pairs of spoilers (spoilers n°1 and n°2) and the redundancy on both outboard ailerons are lost (fig. 2B).

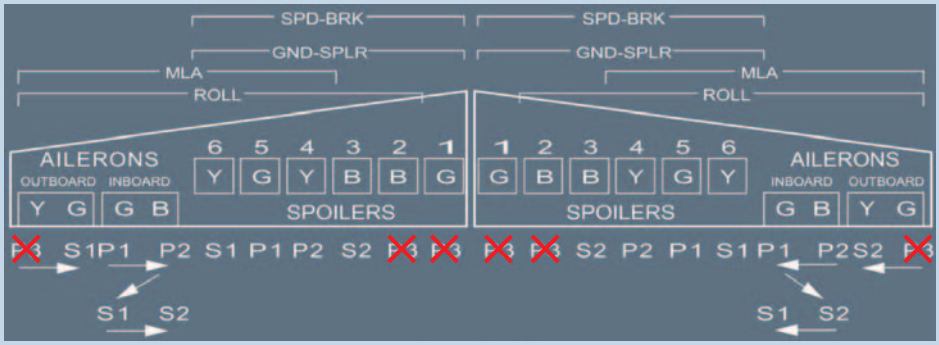


**Figure 2B**
*Loss of PRIM3*

If SEC1 fails in flight, the aircraft loses an additional pair of spoilers (n°6) as well as the left outboard aileron, which goes to its zero hinge moment position(fig. 2C).

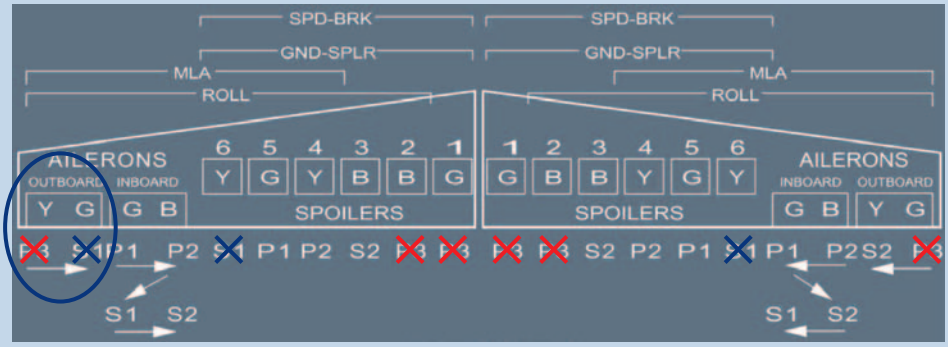


**Figure 2C**
*Loss of PRIM3 and SEC1*

The simple failure of SEC1 taken independently, would have no effect on the fuel consumption. However, combined with the loss of PRIM3, it leads to drag being generated by the left aileron in the zero hinge moment position.

The flight control and landing gear/ landing gear doors malfunctions may be caused by either simple or multiple failures (see explanations in box above).

# 3. Information Provided to the Flight Crew up to Nov 2011

## 3.1 Failures Managed by Ecam

For failures affecting the fuel consumption, a dedicated **"INCREASED FUEL CONSUMP"** message is provided through the associated ECAM STATUS page. However, in the current FWC standards, this line is not displayed for all failures generating a fuel consumption increase (in particular for multiple in-flight failures or for cases of dispatch under MEL) (fig. 3).

To obtain information on the consumption increase, the flight crew had to refer, if time permitted, to the description of the associated ECAM alert in the FCOM. Retrieving this information was therefore left to the pilot's initiative (fig. 4).

## 3.2 Failures Managed by QRH

For failures that were managed through the QRH, the additional fuel consumption information was directly provided in the QRH procedure (like for instance by a caution for the LANDING WITH SLATS OR FLAPS JAMMED procedure) (fig. 5).

# 4. Information Provided to the Flight Crew from Nov 2011

With the QRH revision of November 2011, the procedure has been improved to give better guidance and more comprehensive information. This procedure will be further supported by future Flight Warning Computer (FWC) standards.

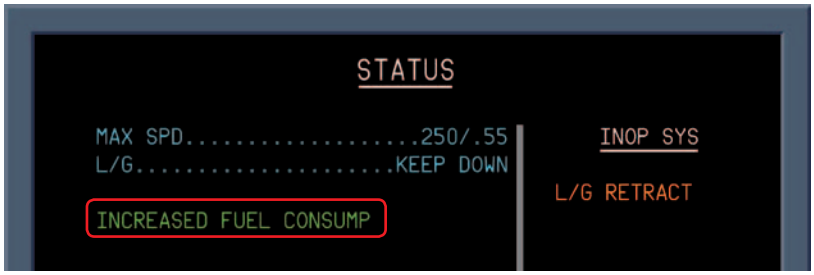


**Figure 3**
*STATUS page of L/G GEAR UPLOCK FAULT*

**L/G GEAR UPLOCK FAULT (Cont'd)**

Ident.: PRO-ABN-32-D-00010765.0001001 / 17 AUG 10
**Applicable to: ALL**

L12

**STATUS**

MAX SPEED..... 250/.55
L/G LEVER..... KEEP DOWN

INCREASED FUEL CONSUMP
*See* (1)

**INOP SYS**

L/G RETRACT

(1) *Flight with the landing gear extended has a significant effect on fuel consumption and climb gradient (Refer to PRO-SPO-25-40 Climb). Multiply fuel consumption by approximately 2.8.*

**Figure 4**
*L/G GEAR UPLOCK FAULT FCOM description*

| | |
|---|---|
| **CAUTION** | For flight with SLATS or FLAPS extended, fuel consumption is increased. Refer to the fuel flow indication. As a guideline, determine the fuel consumption in clean configuration at the same altitude without airspeed limitation (e.g. From ALTERNATE FLIGHT PLANNING tables) and multiply this result by 1.6 (SLATS EXTENDED) or 1.8 (FLAPS EXTENDED) or 2 (SLATS and FLAPS EXTENDED) to obtain the fuel consumption required to reach the destination in the current configuration. |

**Figure 5**
*LANDING WITH SLATS OR FLAPS JAMMED QRH procedure*

## 4.1 QRH Development

All the information on the fuel consumption increase linked to system failures is now gathered in the In-Flight Performance chapter of the QRH (FPE-FPF):

The Fuel Penalty Factors, assessing the fuel consumption increase, are provided through two different tables:

- One table with an entry by ECAM Alerts, and
- One table with an entry by INOP SYS.

**note**

Only the failures leading to a fuel consumption increase greater than 3% have been taken into account in these tables.

### 4.1.1 ECAM Alert Table

For each ECAM alert impacting the fuel consumption, the first table (fig. 6A) provides:

► The critical inoperative system(s) in terms of fuel consumption

► The conditions taken into account to compute the Fuel Penalty Factor, and

► The value of the corresponding Fuel Penalty Factor.

### 4.1.2 INOP SYS Table

For each INOP SYS impacting the fuel consumption, the second table (fig. 6B) provides:

► The conditions taken into account to compute the Fuel Penalty Factor, and

► The value of the Fuel Penalty Factor associated with the INOP SYS.

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## FUEL PENALTY FACTORS/ECAM ALERT TABLE

| SYS | ECAM ALERT | FUEL CRITICAL INOP SYS | CONDITIONS | FUEL PENALTY FACTOR |
|---|---|---|---|---|
| ELEC | AC BUS 1 FAULT (equivalent to B SYS LO PR) | SPLR 3 | If L(R) spoiler 3 is indicated extended (at the time of the failure) | 10 % |
| | DC ESS BUS FAULT (equivalent to B SYS LO PR) | SPLR 3 | If L(R) spoiler 3 is indicated extended (at the time of the failure) | 10 % |
| F/CTL | L(R) AIL FAULT | L(R) AIL | If one aileron is indicated fully extended (upwards or downwards) | 27 % |
| | | L(R) AIL or L+R AIL | If one or both aileron(s) is/are indicated partially extended | 8 % |
| | SPLR FAULT | SPLR (affected) | If one spoiler is suspected fully extended (2)<br>**Cruise Conditions:**<br>**OPT SPEED..... GDOT +10KT**<br>Whenever possible, target green dot speed +10 kt to minimize fuel consumption. However, if buffet is encountered at GDOT speed +10 kt increase speed to fly out of buffet condition.<br>**CRUISE ALT.....AS REQUIRED**<br>Current Flight Level (FL) may not be maintained due to increased drag. Maintain a cruise FL as high as possible. | 55 % |
| | | | If one spoiler or one pair of spoilers is partially extended (zero hinge moment) | 10 % |
| | | SPLR 3 with BLUE HYD | If spoiler 3 is partially extended after the loss of the B hydraulic system (1) | Up to 4 % |
| | | SPLR 1 or 5 with GREEN HYD | If spoiler 1 or 5 is partially extended after the loss of the G hydraulic system (1) | Up to 9 % (3) |
| | | SPLR 2 or 4 with YELLOW HYD | If spoiler 2 or 4 is partially extended after the loss of the Y hydraulic system (1) | Up to 9 % (3) |
| | FLAPS FAULT/LOCKED | FLAPS | If Flaps are extended | 80 % |
| | SLATS FAULT/LOCKED | SLATS | If Slats are extended | 60 % |
| | SLATS + FLAPS FAULT/LOCKED | SLATS+FLAPS | If Slats and Flaps are extended | 100 % |
| HYD | B SYS LO PR | SPLR 3 | If L(R) spoiler 3 is indicated extended (at the time of the failure) | 10 % |
| | G SYS LO PR | SPLR 1+5 | If L(R) spoiler 5 is indicated extended (at the time of the failure) | 10 % |
| | Y SYS LO PR | SPLR 2+4 | If L(R) spoilers 2 and 4 are indicated extended (at the time of the failure) | 20 % |
| | G+B SYS LO PR | L+R AIL SPLR 1+3+5 L ELEV | Both ailerons are failed<br>Spoilers 1, 3 and 5 (1)<br>Left elevator is failed<br>RAT is extended | 10 % to 15 % (4) |
| | G+Y SYS LO PR | SPLR 1+2+4+5 STABILIZER | Stabilizer is jammed<br>Spoilers 1, 2, 4 and 5 (1) | 0 % to 10 % (4) |
| | B+Y SYS LO PR | SPLR 2+3+4 R ELEV | Spoilers 2, 3 and 4 (1)<br>Right elevator is failed<br>RAT extended | 3 % to 10 % (4) |
| L/G | SHOCK ABSORBER FAULT | L/G RETRACT | All landing gears are extended (Also refer to PRO-SPO-25-10) | 180 % |
| | GEAR NOT UPLOCKED | | | |
| | BOGIE ALIGN FAULT (option) | | | |
| | GEAR UPLOCK FAULT | | | |
| | DOORS NOT CLOSED | L/G DOOR | All landing gears doors are extended | 15 % |

**Figure 6A**
*A320 Fuel Penalty Factor table / ECAM alert entry*

*(1) During the flight, the spoiler(s) may gradually extend and increase the fuel consumption.*

*(2) A spoiler can be suspected fully extended (runaway) if high roll rate has been experienced immediately after the failure, associated with a possible AP disconnection. A visual inspection, if time permits, can also confirm the full extension of the spoiler.*

*(3) The maximum value of the Fuel Penalty Factor provided in the table considers that the two pairs of corresponding spoilers gradually extend during the flight.*

*(4) The minimum value of the Fuel Penalty Factor provided in the table considers that all spoilers remain retracted. The maximum value has been calculated considering that all impacted spoilers gradually extend during the flight.*

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## FUEL PENALTY FACTORS/INOP SYS TABLE

| SYS | INOP SYS | CONDITIONS | FUEL PENALTY FACTOR |
|---|---|---|---|
| F/CTL | L(R) AIL or L+R AIL | If one or both aileron(s) is/are indicated partially extended | 8 % |
| | FLAPS | If Flaps are extended | 80 % |
| | SLATS | If Slats are extended | 60 % |
| | SLATS+FLAPS | If Slats and Flaps are extended | 100 % |
| L/G | L/G DOOR | All landing gears doors are extended | 15 % |

**Figure 6B**
*A320 Fuel Penalty Factor table / INOP SYS entry*

### 4.1.3 Utilization of the New QRH Tables

The Fuel Penalty Factors provided in the QRH tables are given as a guideline. The flight crew should confirm this Fuel Penalty Factor by monitoring the actual fuel consumption.

***When should these two QRH tables be used?***

According to the ECAM management philosophy, after the ECAM actions are completed, the flight crew should perform a situation assessment (fig. 7).

The situation assessment by the flight crew has been amended to include an evaluation of the fuel consumption whenever the ECAM STATUS page displays:

► **INCREASED FUEL CONSUMP**

► A flight control surface in the INOPS SYS

► **L/G RETRACT** or **L/G DOOR** in the INOP SYS

To do so, the flight crew should now refer to the Fuel Penalty Factor in the QRH (fig. 8).

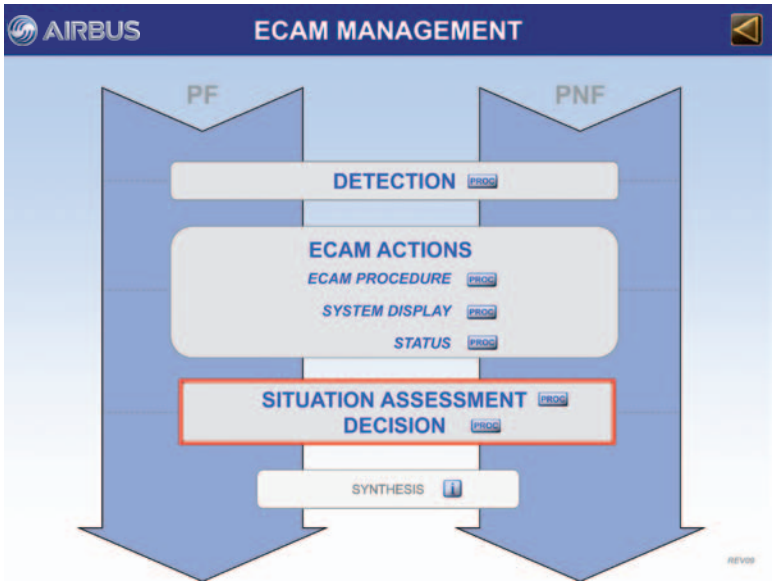



**Figure 7**
*Extract of the Procedure Data Package (PDP) / ECAM Management*

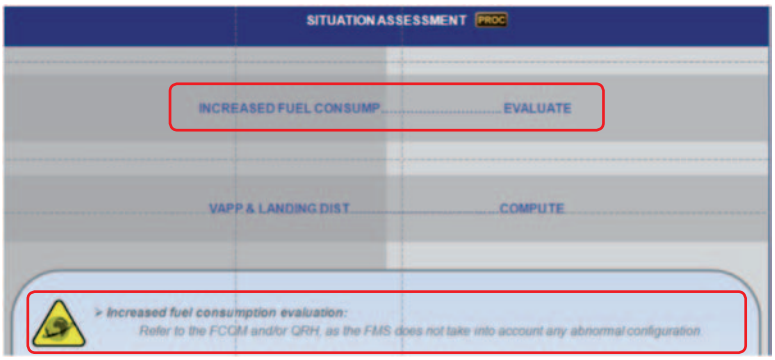



**Figure 8**
*Extract of the Procedure Data Package (PDP) / ECAM Management / Situation Assessment*

***How should these two QRH tables be used?***

The Fuel Penalty Factors in the QRH tables have been calculated taking into account the aircraft configuration, speed or altitude (when mentioned) described in the CONDITIONS column. Ensure that these conditions are well met (or applied) before taking into account the corresponding Fuel Penalty Factor.

To determine whether a Fuel Penalty factor is applicable, the crew needs to proceed in two steps:

► First enter the ECAM alert table, then

► Enter the INOP SYS table.

The second table, INOP SYS, is provided to cover the cases of multiple in-flight failures or dispatch under MEL.

In such cases, two different situations may be encountered:

► The ECAM alert associated with the failure generating the increase of fuel consumption is not mentioned in the ECAM alert table. This is typically the case for failures, which do not impact the fuel consumption when taken independently, but which do lead to an increase in fuel burn when combined with previous failures.

In this circumstance, the flight crew will find the applicable Fuel Penalty Factor in the INOP SYS table.

► The ECAM alert associated with the failure generating the increase of fuel consumption is mentioned in the ECAM alert table. However, due to previous failures, an additional INOP SYS on the STATUS page (different from the one(s) mentioned in the FUEL CRITICAL INOP SYS column for the corresponding ECAM alert) has an impact on the fuel consumption.

In that circumstance, the flight crew will find another applicable Fuel Penalty Factor in the INOP SYS table.

Once the pertinent Fuel Penalty Factors have been identified, the procedure is as follows:

► If only one Fuel Penalty Factor (FPF) is applicable:

**ADDITIONAL FUEL =**
**(FOB - EFOB at DEST) x FPF**

► If two or more Fuel Penalty Factors (FPF) are applicable:

**ADDITIONAL FUEL =**
**(FOB - EFOB at DEST)**
**x (FPF1 + FPF2 +...)**

This ADDITIONAL FUEL must be added to the fuel predictions provided by the FMS.

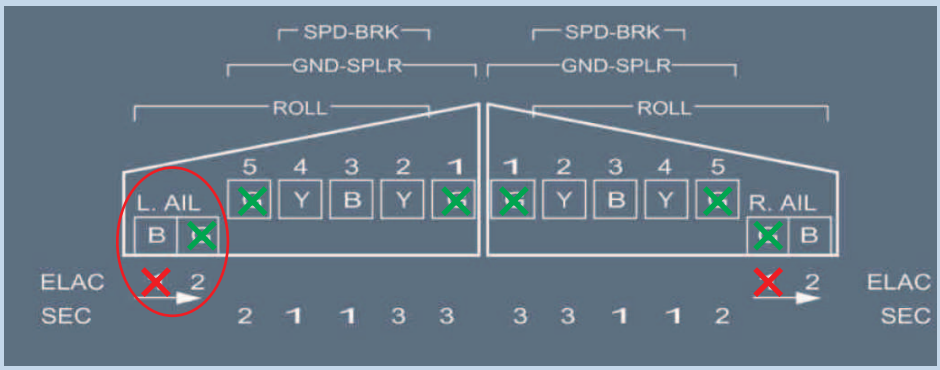
## Example of Utilization of QRH tables

To illustrate the method, let us consider an A320 under the following conditions:

► A dispatch with the ELAC 1 inoperative under MEL, and

► An HYD G SYS LO PR ECAM caution in flight

These two failures lead to the loss of the left aileron:




Therefore, the INOP SYS will display "L AIL" that should lead the flight crew to enter the QRH Tables.

In the ECAM alert table:

FPF (HYD G SYS LO PR) = 10 %
(if spoiler(s) are indicated extended)

In the INOP SYS table:

FPF (INOP SYS: L AIL) = 8 %

Two possible cases may be encountered:

► If the Fuel Penalty Factor of the HYD G SYS LO PR ECAM alert is not applicable (spoiler remains retracted), apply the Fuel Penalty Factor related to the INOP SYS "L(R) AIL" partially extended.

**ADDITIONAL FUEL = (FOB - EFOB at DEST) x 8 %**

► If the Fuel Penalty Factor of the HYD G SYS LO PR ECAM alert is applicable (spoiler extended), add the corresponding factor to the Fuel Penalty Factor related to the INOP SYS "L(R) AIL" partially extended.

**ADDITIONAL FUEL = (FOB - EFOB at DEST) x (10 % + 8 %)**

### 4.2 ECAM Development

With future Flight Warning Computer (FWC) standards, all failure cases leading to an increase in fuel consumption of more than 3%, including multiple in-flight failures and dispatch under MEL, will trigger a **"FUEL CONSUMPT INCRSD"** message on the ECAM STATUS page. This message will be complemented with a **"FMS PRED UNRELIABLE"** line to highlight the unreliability of the FMS (fig. 9).

The same wording will also be used in the associated ECAM procedure.

All these improvements will be introduced in the following FWC standards:

► A320 Family: H2F7 standard (certification planned for December 2012)

► A330 and A340-500/600: T5 standard (certification planned for January 2013)

► A340-200/300: L13 standard (certification planned for August 2013).


**Figure 9**
*Future A330 STATUS page of the F/CTL L(R) INR (OUTR) AIL FAULT*

## 5. CONCLUSION

After an in-flight failure, it is essential for the flight crew to have a clear view of all the operational consequences generated by this failure. In particular, when the fuel consumption is affected, the pilot should have means to estimate this impact.

This is the purpose of this new policy supported by new QRH tables and future developments implemented in the next FWC standards. The information is now concentrated in one part of the Operational Documentation (simplified access), takes into account more operational cases (multiple failure, dispatch under MEL), and the associated procedure is more formalized.

This policy ensures a standardized and common treatment of all the failures impacting the fuel consumption, by giving the same level of information to all flight crew.

It improves crew awareness on consequences of such failures, and as a result, represents a new step in the safety of airline operations.

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**A320**
*Close up on new A320 sharklet*

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